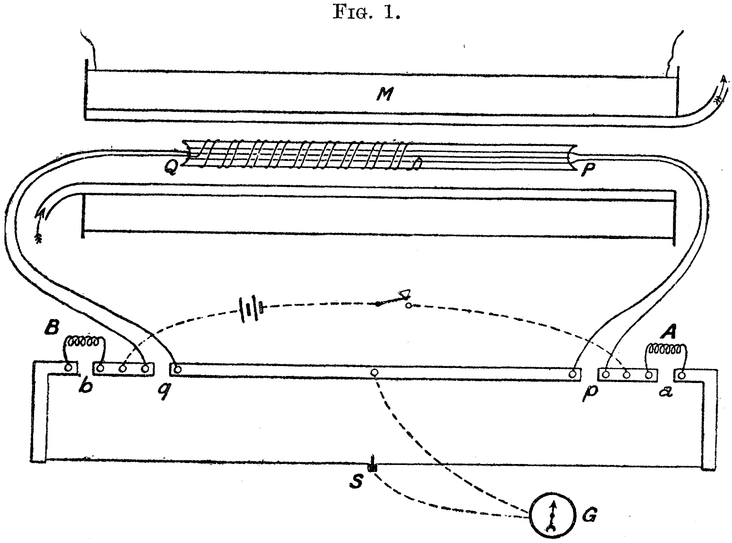
"On the Change of Resistance in Iron produced by Magnetisation." By ANDREW GRAY, LL.D., F.R.S., Professor of Natural Philosophy in the University of Glasgow, and EDWARD TAYLOR JONES, D.Sc., Professor of Physics in the University College of North Wales. Received May 30,—Read June 21, 1900.

The experiments described below were made with the object of determining simultaneous values in a specimen of soft iron wire of the magnetising force, the magnetisation, and the change of resistance due to magnetisation. In all the measurements hitherto made of magnetic changes of resistance no attempt seems to have been made to determine at the same time the magnetisation; in fact, the results which have been obtained for bismuth might appear to indicate that there is but little, if any, connection between magnetisation and change of resistance. The results herein described, on the other hand, indicate that there is a somewhat close connection between the two phenomena, and make it clear that further measurements on similar lines would have some value.

Measurement of Resistance.

Preliminary trials showed that great difficulty would be experienced in determining the magnetic change of resistance in iron unless great precautions were taken to eliminate the effects of rise of temperature in the wires due to the passage of even feeble currents. In the arrangement finally adopted, *two* coils of soft iron wire P, Q (fig. 1)

FIG. 1.



were used, of nearly equal lengths, cut from the same specimen, and doubly wound with silk. One of these was wound longitudinally, the other spirally and non-inductively, on a rod of wood about 60 cm. long. The whole was placed inside a magnetising coil, so that one coil, P, became longitudinally, the other, Q, transversely magnetised.

On account of the great demagnetising factor for a cylinder magnetised transversely, however, the latter coil was only very feebly magnetised. The magnetising coil was 1 metre long, and was provided with a double cylindrical core through which a constant stream of water could be kept flowing, in order to diminish the heating effect of the magnetising current. It was further arranged in the experiments that equal currents should flow in the two iron coils, which were thus subjected to very approximately equal rises of temperature. These arrangements, though not perfect, so much diminished and retarded the heating effects of currents in the various coils that these could be readily distinguished from the magnetic effect.

The comparison of the resistances of the coils P, Q was carried out in the usual way. The platinoid wire of the bridge was replaced by one of somewhat thick copper, so as to give an easily measurable step of the slider for the small alteration of the ratio of resistances of the coils which had to be measured, the iron coils inserted in p, q (fig. 1), and two nearly equal coils A, B in a, b. A and B were both kept in one bath of oil. All connecting wires were of thick copper. The galvanometer was a Kelvin low-resistance astatic instrument. The magnetising current was measured by a Kelvin graded galvanometer, standardised by electrolysis and by comparison with a Kelvin deciampere balance.

In making observations, the iron coils P, Q were first demagnetised by reversals, and the position of the sliding contact key S found, which gave no galvanometer deflection.

Then a weak magnetising current was applied, reversed several times, and the position of S again found. The change of position of S indicated that the resistance of the longitudinally magnetised wire became greater than that of the transversely magnetised wire. This was repeated for a large number of field-strengths, each greater than the one preceding it. The resistances of the auxiliary coils A, B were so chosen that the change of position of S with the greatest magnetising field used amounted to about 16 cms. The difference of the fractional increments of resistance of P and Q $\left(\frac{\Delta P}{P} - \frac{\Delta Q}{Q} = \Delta\phi\right)$ was calculated from the observed displacement of S from its zero position, and the results given below represent values of $\delta\phi$ for different field-strengths.

Measurement of Magnetisation.

The magnetisation of the iron was determined in separate experiments. For this purpose a narrow glass tube, 60 cm. long, was filled with a number of lengths of iron wire, cut from the same specimen, from which the insulation had been removed. A number of turns of fine insulated copper wire was wound on the glass tube near its middle and connected to a ballistic galvanometer, standardised by solenoid and secondary coil. The tube, with the lengths of iron wire, was placed within the magnetising coil, and the BH curve of ascending reversals was determined for the iron in the usual way, and the magnetisation I calculated from the equation $I = B - H/4\pi$. No account was taken of the demagnetising factor of the iron wires; the factor for a cylinder of the same length and of cross-section equal to the sum of the section of the thirteen pieces of wire in the glass tube is but of the order 0·0008.

Results.

The following are particulars as to the coils, &c., used :—

Diameter of soft iron wire used in resistance and magnetisation experiments	0·0745 cm.
Resistance of iron coil P (longitudinally wound)...	1·045 ohms.
Resistance of iron coil Q (spirally wound)	1·118 ,,
Do., do., auxiliary coil A	1·382 ,,
Do., do., auxiliary coil B	1·476 ,,

The coils A, B were of German silver. Resistance per centimetre of bridge wire (σ) = 0·0000536 ohm. The difference of the fractional increments of resistance of P and Q was calculated from the approximate equation

$$\Delta\phi = \frac{\Delta P}{P} - \frac{\Delta Q}{Q} = \frac{A+B}{AB}\sigma\delta x,$$

where δx is the displacement of the contact S (fig. 1) from its zero position, *i.e.*, from its position when the wires were not magnetised.

The mean temperature of the iron wire during both the change of resistance and the magnetisation measurements, determined by frequently observing the temperature of the water entering and leaving the magnetising coil, was 5·5° C.

The results of all the measurements are shown in the accompanying curves. Fig. 2 is the magnetisation curve (I, H, c.g.s.) of ascending reversals. Fig. 3 the curve B, H for the longitudinal coil. Fig. 4 shows $\Delta\phi$ as a function of the magnetising field H. The general resemblance between this curve and the magnetisation curve suggests that the change of resistance depends on the magnetisation rather than on magnetising force.

FIG. 3.

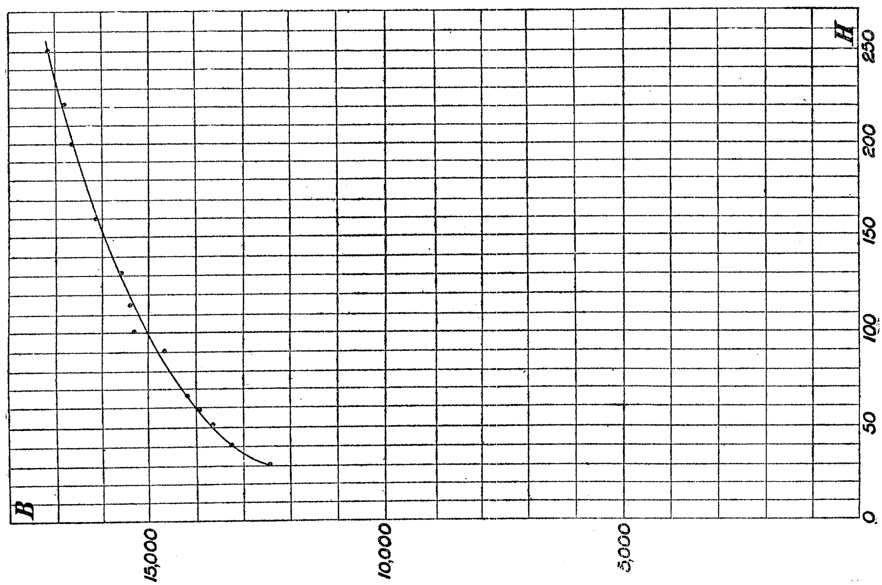

B
15,000
10,000
5,000
H
0
50
100
150
200
250

FIG. 2.

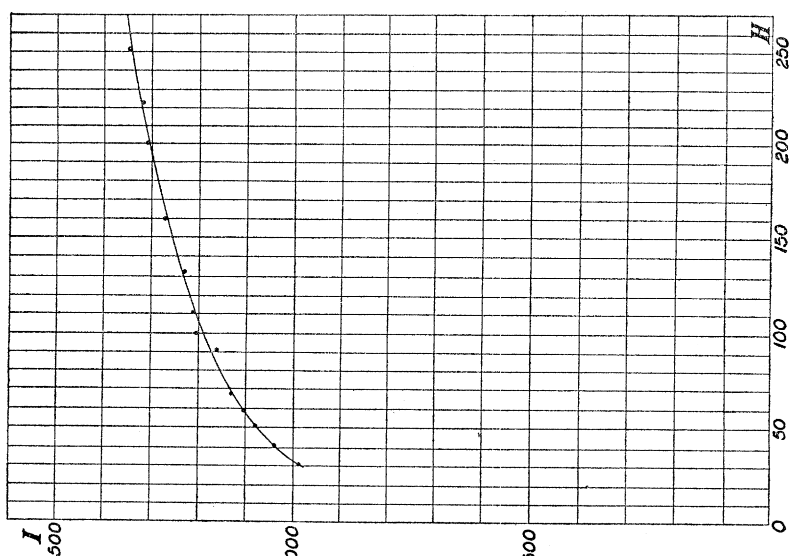
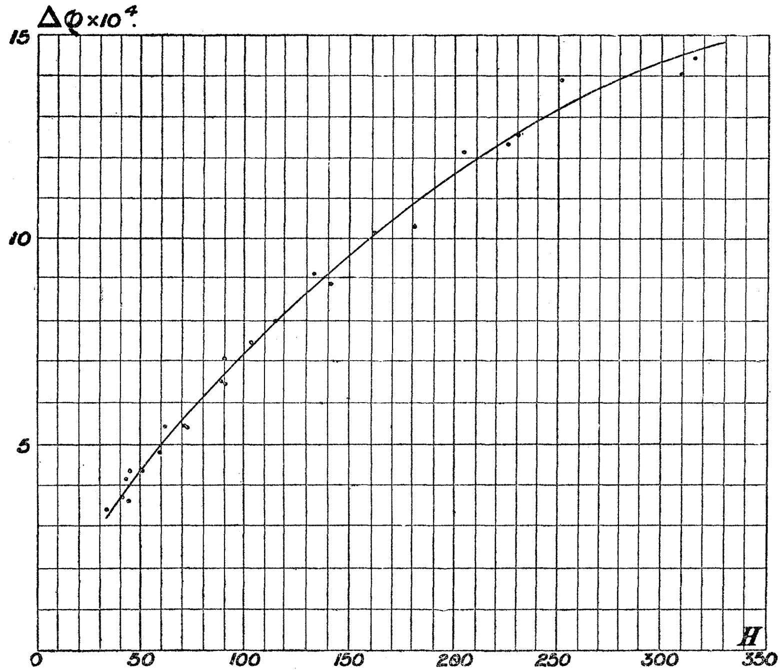

I
1,500
1,000
500
H
0
50
100
150
200
250

Fig. 4.



Figs. 5, 6, 7 show $\Delta\phi$ as a function of B^4, I^4, I^6 respectively.

Of these, fig. 6 approximates closely to a straight line except in the neighbourhood of the origin. It may thus be stated as an empirical result for the specimen of soft iron and for the range of magnetisation employed in these experiments that the change of resistance is approximately proportional to the fourth power of the magnetisation.

Note added, June 18.—The results are complicated to some extent by hysteresis. It was found that when the iron wires were first thoroughly demagnetised, and after having been left long enough to take the temperature of the surroundings, were subjected to a rather strong magnetising current, kept in for less than a second, so that no appreciable heating could arise, about a third of $\delta\phi$ remained after the magnetic force was removed.

The above experiments were carried out in the Physical Laboratory of the University College of North Wales, and we wish to take this opportunity of expressing our high appreciation of the value of the assistance of two students of the College, Mr. Guy Barlow and Mr. Godfrey Rotter, who, by making many measurements and calculations, enabled us to complete the work.

FIG. 5.

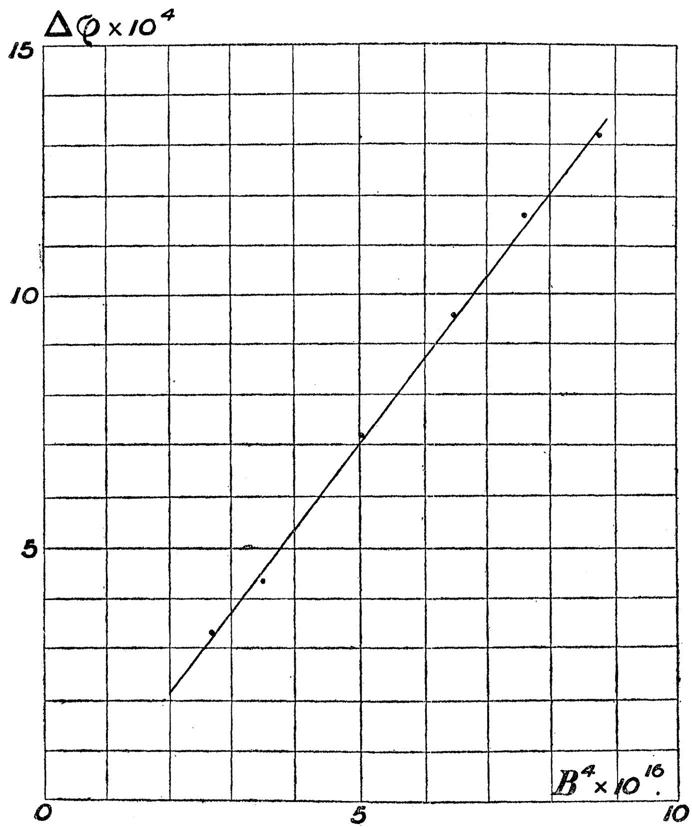


Fig. 6.

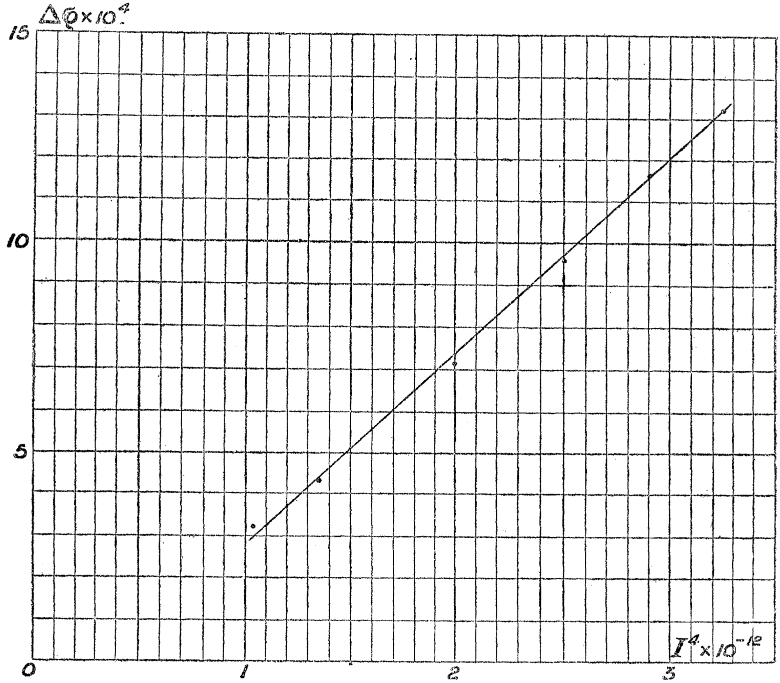


FIG. 7.